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THE EXCEPTIONAL HEAT-WAVE OF 23 JUNE TO 8 JULY 1976

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Summary

The heat-wave of 23 June to 8 July 1976 was associated with a stable high-pressure system over England and Wales, both at the surface and at high levels. Minor day-to-day changes in the velocity of the surface wind determined the location of the hottest areas. Temperature returns from about 630 official and co-operating stations in the United Kingdom were examined and they showed that, on a criterion of number of days with temperature equal to or greater than 32°C (90°F), the 1976 heat-wave far exceeded all others. Although the highest individual temperature of 35·9°C at Cheltenham on 3 July was lower than the most probable United Kingdom record, individual records were broken at more than 30 stations and temperatures having return-periods of more than 50 years were recorded over most of southern England and also over parts of the Scottish Borders and the Highlands. More than twice the average amount of sunshine was recorded over most of England and Wales. Humidities were generally low, and occasionally exceptionally so.

Introduction

One of the outstanding features of the weather over the British Isles during the remarkable summer of 1976 was a prolonged heat-wave which lasted for more than two weeks over parts of central and southern England during late June and early July. It now seems certain that this hot spell was both the longest and the most extensive heat-wave experienced in the United Kingdom for at least 100 years and probably much longer. Temperatures exceeded 32°C at one or more stations in the United Kingdom on every day from 23 June to 7 July inclusive, and Cheltenham (Gloucestershire) had 11 such days including 7 in succession from 1 July.

Starting on 23 June over East Anglia the heat-wave intensified to reach a peak over eastern England on 26 June and then extended to Wales, south-west and northern England, south and east Scotland and Northern Ireland by 29 June and to the remainder of the Scottish mainland by 1 July. Over England and Wales, temperatures fell slightly for two or three days from 29 June before reaching a second peak on 3 July when maxima were higher than in June in many western districts. The hot spell came to an end when cooler air spread slowly from the Atlantic to reach Northern Ireland by 6 July and almost all remaining parts of the United Kingdom by the 9th.

Although the highest temperatures were confined to parts of East Anglia, the Midlands and central southern England, local long-period temperature records were broken at numerous stations throughout the United Kingdom including places as far apart as the west of Cornwall, the Scottish Highlands and Co. Fermanagh. Coastal temperatures were generally lower than those inland, but on several days sea-breezes were not effective and remarkably high temperatures occurred, particularly along the south coast of England.

Skies remained almost cloudless over much of central and eastern England, parts of East Anglia, Kent and East Sussex having an average of more than 14 hours' bright sunshine a day over the 16 day period. A few very isolated thunderstorms broke out during the second week in eastern and central parts of England but over most of the area the air remained unusually dry and stable throughout the heat-wave. On 30 June exceptionally dry air reached the surface over a wide area of East Anglia and southern England, relative humidities of less than 20 per cent being reported from many stations over a period of several hours.

2. Synoptic situation and evolution of the heat-wave

(a) *General upper-air and surface developments*

During the first half of June a ridge of high pressure was maintained across Biscay, northern France and southern England under a weak anticyclonic upper flow; little or no rain fell over these areas which were already suffering from a severe rainfall deficiency extending back for over twelve months, and high temperatures were recorded on several days although no prolonged hot spell occurred. A temporary change in the situation took place between 17 and 20 June as an upper westerly flow became established over the British Isles and on the 19th a small wave depression crossed South Wales, the Midlands and East Anglia, bringing moderate falls of rain to many places in southern England. A steady rise of pressure took place behind the depression, and by the 21st a broad belt of high pressure was established from Spain to the southern North Sea with low pressure in mid-Atlantic and over Finland.

The upper-air pattern at this time showed an almost stationary vortex over the Atlantic to the south-west of Iceland, a mobile trough over the Baltic, and, between these features, a developing upper ridge over the British Isles. Over the next week this ridge amplified and swung slowly south-east as geopotentials increased over western Europe, and by 28 June a large upper high covered England, Wales and northern France while Scotland and Northern Ireland lay under a light westerly flow. Weak fronts moving east continued to affect Scotland and Northern Ireland until the end of June, but on 1 July the upper ridge extended north-westwards so that the upper high covered the whole of the United Kingdom. Eastern parts of England and Scotland subsequently remained under the influence of this high until 8 or 9 July and upper-air ascents remained very dry and stable; elsewhere, however, moister, unstable air ahead of a very slow-moving upper trough edged slowly and erratically into western and central districts, giving increasing cloud and a few isolated thunderstorms. By 8 July the centre of the upper high had moved to the north of Scotland, leaving a broad ridge across the North Sea, and, as geopotentials continued to increase over Iceland and Norway and to decrease over the North Sea, a south-westerly flow extended slowly east to reach all parts of the United Kingdom by 10 July.

Underneath this stable upper-air pattern, surface pressure changes were relatively small. However, as the location of the hottest areas from day to day

was largely determined by the speed and direction of the surface winds, even small changes affecting the positions of the high centres were important. The heat-wave could be divided into two separate and almost equal phases, and the evolution of the 16 day hot spell shown by the sequence of charts in Figure 1 is discussed in the following sections. The eight days shown in Figure 1 were selected to document significant variations in the pattern of the highest temperatures, and so are not at regular intervals throughout the period.

(b) *The first phase of the heat-wave, 23–30 June*

The high-pressure centre which had developed over the English Channel on 21 June drifted slowly east into northern Germany by the 23rd and light southerly winds brought hot, dry air from northern France across a large area of south-east England and East Anglia, where temperatures rose to above 30°C in many places (Figure 1(a)). By 25 June a flat area of high pressure with very light, variable winds covered the whole of England and Wales, and under cloudless skies temperatures rose to be several degrees higher than on previous days; the whole of London together with parts of East Anglia reported temperatures higher than 32°C for the first time. The heat-wave reached its first peak on the following day, 26 June, when temperatures rose by a further 2°C over the whole of eastern England (Figure 1(b)); over 30 stations reported maxima $\geqslant$34°C and except in a coastal strip from Lincolnshire to Sussex, maxima at all stations south-east of a line from Bournemouth to Hull exceeded 32°C. During the day a weak cold front crossed Scotland and Northern Ireland and, as pressure rose behind the front, the axis of the dominant ridge of high pressure was transferred northwards, and light north-easterly winds set in over southern England. The effect of these winds was apparent on 27 and 28 June as maximum temperatures fell slightly in the east but rose to almost unprecedented levels at south coast resorts and over much of south-west England and South Wales (Figure 1(c)).

Up to this time the heat-wave had been largely confined to the southern half of England and South Wales, but as a centre of high pressure became established over the central North Sea during 28 and 29 June temperatures over much of northern England, North Wales and parts of Northern Ireland rose above 28°C for the first time during the heat-wave. Further south, however, temperatures fell from their previous levels as strengthening north-easterly winds blew from the North Sea; much of East Anglia, the London area and south-east England were 4°C cooler on 29 June than on previous days. The last day of June proved to be the 'coolest' day of the heat-wave. A cold front moved south across Scotland to become stationary near the English Border and, to the north of this front, a mobile anticyclonic cell moved east to reinforce and intensify the high pressure over the northern North Sea. Temperatures over Scotland fell sharply behind the front while maxima over Wales and western England also fell as strengthening easterly winds spread across the country (Figure 1(d)); Northern Ireland, however, remained in light south-easterly winds to the south of the front, and temperatures rose to record levels at some stations in the west of the Province.

(c) *The second phase, 1–8 July*

Pressure remained high on 1 July over the northern North Sea and strong easterly winds continued to blow over England and Wales, but over Scotland maximum temperatures were substantially higher than on the previous day as the frontal zone returned northwards and warm, southerly winds spread to all parts

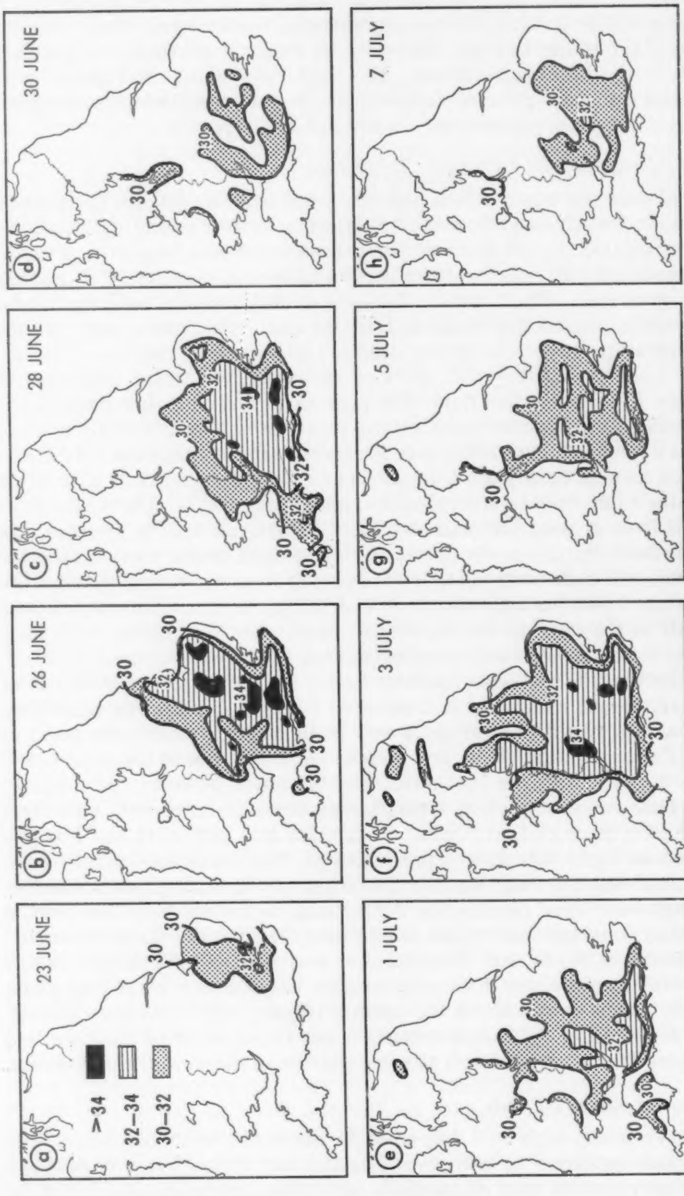

FIGURE 1—MAXIMUM TEMPERATURES (°C) ON SELECTED DAYS DURING THE HEAT-WAVE OF 1976

(Figure 1(e)). A change took place in the pressure pattern over the next two days as the high over the North Sea declined and moved away south-east while a new anticyclone developed between Iceland and Norway. A very light south-easterly flow brought hot, dry air north from northern France and the Low Countries to all areas of the United Kingdom and temperatures on 3 July rose to their highest levels of the entire heat-wave at many stations, particularly in the west. Figure 1(f) shows that temperatures in excess of 32°C were reported from an area of approximately 50 000 km² extending from Somerset and Lancashire in the west to Kent and Norfolk in the east. A few isolated thunderstorms broke out in central and eastern England but most places remained sunny and dry.

On 4 July a ridge of high pressure built southwards across the North Sea from the anticyclone to the north of Scotland and this pattern was subsequently maintained with only minor changes until 8 July. Light to moderate easterly winds accompanied by cloudless skies and maximum temperatures only slightly below their peak values persisted over most of England, Scotland and Wales throughout this period (Figure 1(g)). South-west England, west Wales and Northern Ireland meanwhile became progressively more cloudy with rain or thunderstorms at times as an occlusion edged very slowly into these districts from the west. Temperatures in Northern Ireland returned to normal on 6 July but the encroachment of cooler, Atlantic air further south was so slow and irregular that it took a further two days for the front to clear Wales and south-west England (Figure 1(h)). Ahead of the occlusion temperatures still remained very high on 8 July, but a strengthening upper south-westerly flow carried variable cloud and occasional light rain steadily north-east to all parts of the country during the 9th to bring the remarkable heat-wave to a surprisingly quiet and uneventful end.

3. The data and checks applied to them

Monthly returns of data are received at the Climatological Services Branch, Bracknell, and at offices in Edinburgh and Belfast, from approximately 630 Meteorological Office and co-operating stations in the United Kingdom. A quality control check is carried out on all these data to ensure consistency of observations at any one station and to query large discrepancies between observations at neighbouring stations. Such objective quality control methods are, of necessity, fairly coarse and during the period of the hot spell a more detailed check on the reported temperatures was carried out by using charts of maximum temperature which were plotted for each of the 16 days from 23 June to 8 July inclusive. All temperatures that appeared questionable on these daily charts were carefully examined in the light of the temperature pattern of neighbouring stations, the synoptic situation and site characteristics. Sequences of daily maximum temperature observations at individual stations were also examined and compared with similar sequences for nearby stations as a further method of assessing doubtful readings. Several particularly high temperatures checked in this way were considered unacceptable, including the temperature of 36·0°C at Plumpton (East Sussex) referred to by Ratcliffe (1976) and a summary of the case for not accepting this value has been given by Shaw (1977).

Maximum-temperature observations for a selection of stations throughout the 16 day period are given in Table I. Only reports from Meteorological Office and co-operating stations whose observing sites and procedures are periodically inspected by professional staff have been used in this paper.

TABLE I—DAILY MAXIMUM TEMPERATURES (°C) FOR 23–30 JUNE (A) AND 1–8 JULY (B)

	Grid Ref.										*Average*
Manchester Airport	SJ 818850	(A)	24·5	25·3	26·9	26·6	28·3	29·2	31·3	29·7	29·1
		(B)	30·0	31·5	32·2	30·2	30·2	30·6	29·8	28·7	
Derby	SK 359367	(A)	28·0	28·9	30·4	30·9	31·4	31·5	30·9	28·9	30·5
		(B)	30·5	31·9	32·7	30·9	31·1	30·6	29·7	30·2	
Lincoln	SK 962719	(A)	28·9	28·7	30·1	32·0	31·9	27·0	28·1	25·8	28·6
		(B)	26·5	29·3	30·5	28·1	27·8	27·5	27·0	27·8	
Shrewsbury	SJ 517136	(A)	25·0	26·5	28·9	28·7	30·4	30·5	31·1	29·7	29·7
		(B)	30·9	31·6	32·8	31·0	29·9	30·2	29·1	28·1	
Coventry	SP 348743	(A)	27·7	28·1	30·5	32·4	32·0	32·1	30·2	29·9	30·9
		(B)	31·0	32·6	33·0	30·5	31·7	31·5	30·2	30·2	
Cambridge (Botanic Garden)	TL 456572	(A)	31·0	30·5	33·0	34·0	33·8	32·0	30·5	30·0	31·8
		(B)	29·7	32·5	33·5	33·8	32·4	31·7	30·6	30·5	
Cheltenham	SO 946218	(A)	28·2	29·4	31·6	34·6	34·0	34·5	32·3	30·5	32·7
		(B)	32·1	35·7	35·9	34·1	33·0	34·3	32·7	30·9	
Oxford (Radcliffe Obsy)	SP 509072	(A)	28·8	29·5	32·0	34·0	34·3	33·1	30·7	30·2	31·8
		(B)	30·4	33·0	33·4	32·4	32·5	32·6	31·1	30·8	
Kew (North Wall screen)	TQ 171757	(A)	31·3	30·5	32·8	34·6	34·2	33·1	29·1	29·3	31·7
		(B)	29·2	31·2	34·1	33·2	31·6	32·3	30·6	30·7	
Exeter	SY 001933	(A)	25·9	24·5	28·4	32·1	33·5	33·0	31·4	29·6	29·3
		(B)	30·0	29·2	31·9	30·1	30·2	28·6	24·6	25·4	
Southampton (Mayflower Park)	SU 416112	(A)	26·1	27·1	30·1	34·9	35·5	35·6	32·2	32·1	31·5
		(B)	32·6	31·5	30·8	31·5	33·1	32·6	30·7	26·9	
Gatwick Airport	TQ 265407	(A)	29·5	30·1	32·2	33·8	33·3	33·5	29·2	28·2	31·3
		(B)	29·7	32·3	33·9	32·2	30·9	31·7	30·0	29·8	

For each station the top row of temperatures is for 23–30 June, and the bottom row for 1–8 July. The average for the whole 16 day period is given in the final column.

4. COMPARISON WITH PREVIOUS HEAT-WAVES

(a) *Highest temperatures reached*

Figure 2 shows the highest temperatures reached at stations throughout the country during the period from 23 June to 8 July inclusive. Variations within the area of highest maxima in southern England are largely a reflection of topographical detail, the highest values being reported from low-lying inland stations in East Anglia, the Thames and Severn valleys and southernmost counties from Somerset to Sussex. It has been suggested by Hopkins and Whyte (1975) that a temperature reduction of 1°C for each 100 m increase in altitude is appropriate for extreme values of maximum temperature. A check during this particular heat-wave using the highest maxima at 10 pairs of neighbouring high-level and low-level inland stations produced an average fall with height of 1·1°C/100 m, but the range of lapse rates was substantial (0·5 to 1·75°C/100 m) which indicates that altitude is only one of several factors to be considered. The unusually high temperatures attained at some coastal stations show up on Figure 2 and these will be discussed more fully in section 5 of this paper.

The highest accepted temperatures recorded in the United Kingdom on each day during the heat-wave are shown in Table II and a list of the highest temperatures overall appears in Table III. From these tables the following points are of particular interest:

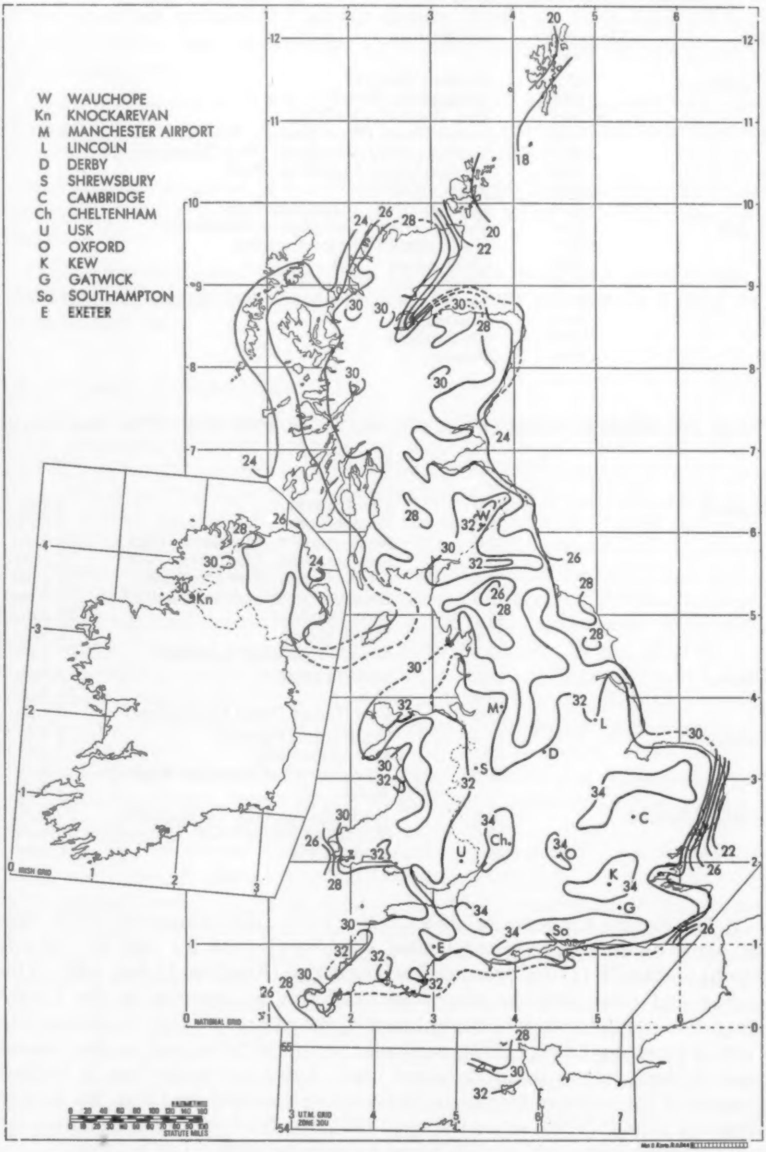

FIGURE 2—HIGHEST TEMPERATURES (°C) REPORTED DURING THE 16 DAYS FROM 23 JUNE TO 8 JULY 1976

TABLE II—HIGHEST MAXIMUM ON EACH DAY OF THE HEAT-WAVE

Date	Max. temp. °C	Location
23 June	32·2	Maldon (Essex)
24	32·4	Gillingham (Kent)
25	33·5	East Bergholt (Suffolk)
26	35·4	North Heath (West Sussex); East Dereham (Norfolk)
27	35·5	Southampton, Mayflower Park (Hampshire)
28	35·6	Southampton, Mayflower Park
29	33·6	Totnes (Devon)
30	32·1	Southampton, Mayflower Park
1 July	33·5	Yeovilton and Cannington (Somerset)
2	35·7	Cheltenham (Gloucestershire)
3	35·9	Cheltenham
4	34·1	Cheltenham; North Heath
5	33·1	Southampton, Mayflower Park; Benson (Oxfordshire)
6	34·3	Cheltenham
7	32·7	Cheltenham
8	31·1	Benson

TABLE III—HIGHEST TEMPERATURES OVERALL DURING THE 1976 HEAT-WAVE

	Temperature °C	Location	Date
England	35·9	Cheltenham	3 July
	35·7	Cheltenham	2 July
	35·6	Southampton, Mayflower Park	28 June
	35·5	Southampton, Mayflower Park	27 June
	35·4	North Heath; East Dereham	26 June
	35·3	Southampton Weather Centre	27 June
	35·1	East Dereham	27 June
	35·0	North Heath	2 July
		Waddon (Greater London)	26 June
Wales	33·6	Usk (Gwent)	3 July
	33·5	Usk	28 June
	33·2	Port Talbot (West Glamorgan)	2 July
Scotland	32·4	Wauchope (Borders)	2 July
	32·1	Kelso (Borders)	2 July
	31·6	Lossiemouth (Grampian Region)	1 July
		Kelso	3 July
Northern Ireland	30·8	Knockarevan (Co. Fermanagh)	30 June
	30·0	Strabane Convent (Co. Tyrone)	30 June
	29·2	Knockarevan	1 July

(1) The highest temperature, 35·9°C (96·6°F) at Cheltenham on 3 July, falls well short of the often quoted United Kingdom record for July (or for any month) of 100·5°F (38·1°C) recorded at Tonbridge (Kent) on 22 July 1868. This reading and other extreme maximum temperatures reported in the United Kingdom since the middle of the last century have been critically re-examined in a recent paper by Laing (1977), particular attention being paid to the various types of thermometer stand or screen used. Laing concludes that 'a realistic estimate of the extreme maximum temperature recorded so far in the United Kingdom' is 98°F (37°C) set on 9 August 1911; the Tonbridge reading is assessed as having been between 97 and 98°F and remains the highest July reading.*

* For temperature values reported during previous heat-waves to the nearest whole °F, the equivalents in °C have been calculated to the nearest ½°C.

(2) The highest *June* temperature, 35·6°C (96·1°F) at Southampton on the 28th equals that reached at Camden Square (London) on 29 June 1957, the previous highest June temperature ever officially recorded anywhere in the United Kingdom.

(3) The maximum of 33·6°C (92·5°F) at Usk on 3 July falls only fractionally short of the temperature of 93°F (34°C) reached at Newport (Gwent) in July 1923 which is believed to be the highest ever recorded in Wales.

(4) The temperature of 32·4°C (90·3°F) at Wauchope (Borders) on 2 July was the highest for any month in Scotland since 1908 when 91°F was recorded at Dumfries.

(5) The temperature of 30·8°C (87·4°F) at Knockarevan (Co. Fermanagh) on 30 June was the highest ever recorded in any month in Northern Ireland since records began there.

(b) *The length of the heat-wave*

Although neither the start nor the finish of the hot spell was marked by very large temperature changes, the period was nevertheless fairly well defined. Figure 3 shows the number of consecutive days having maxima ⩾28°C during the period from 23 June to 8 July inclusive; 59 stations are included in the areas having 16 such days but at no station did the spell extend to 17 days, although a few places in eastern Britain did exceed 28° C on 9 July. If the threshold is raised to 30°C the long spell is broken in most eastern districts but three stations (Cardington (Bedfordshire), Hoddesdon (Hertfordshire) and London/Heathrow Airport) recorded 16 successive days with maxima ⩾30°C, and, further west, 14 or 15 days were widely reported over central southern England. At the 32°C level no coherent pattern emerges, but most stations in southern England from Devon to Essex, and including the Greater London area, had 3 or 4 consecutive days and at many places two such periods were broken by the cooler days at the end of June. The longest unbroken sequences of maxima ⩾32°C were 7 days at Cheltenham (Gloucestershire) and 6 days at Innsworth (Gloucestershire), Benson (Oxfordshire), North Heath, Rogate and Fernhurst (all in West Sussex) and at Mayflower Park in Southampton.

In Scotland the longest spell of hot weather occurred in the south and south-west, where several stations reported 11 successive days, from 28 June to 8 July, with maxima over 25°C; in the south-east, where temperatures in general were slightly higher, the spell was reduced to 8 days owing to the much lower temperatures on 30 June. Over Northern Ireland the hot spell also started on 28 June and continued unabated until 5 July; several inland stations in the south and west had 8 successive days when 25°C was reached, and at two stations temperatures of 28°C were exceeded on each of the 7 days from 28 June to 4 July.

A temperature of 32·2°C (90°F) is quite rare in the British Isles and it is almost certain that no spell of more than 4 consecutive days with temperatures in excess of 90°F had ever been reliably recorded in a Stevenson screen anywhere in the country before 1976. Since the middle of the last century many letters and articles have been published concerning occasions of great heat, but reference can be found to only six occasions on which 4 and one occasion on which 5 successive days have been recorded. These instances are listed in Table IV together with the longest spells during the 1976 heat-wave. It will be seen that

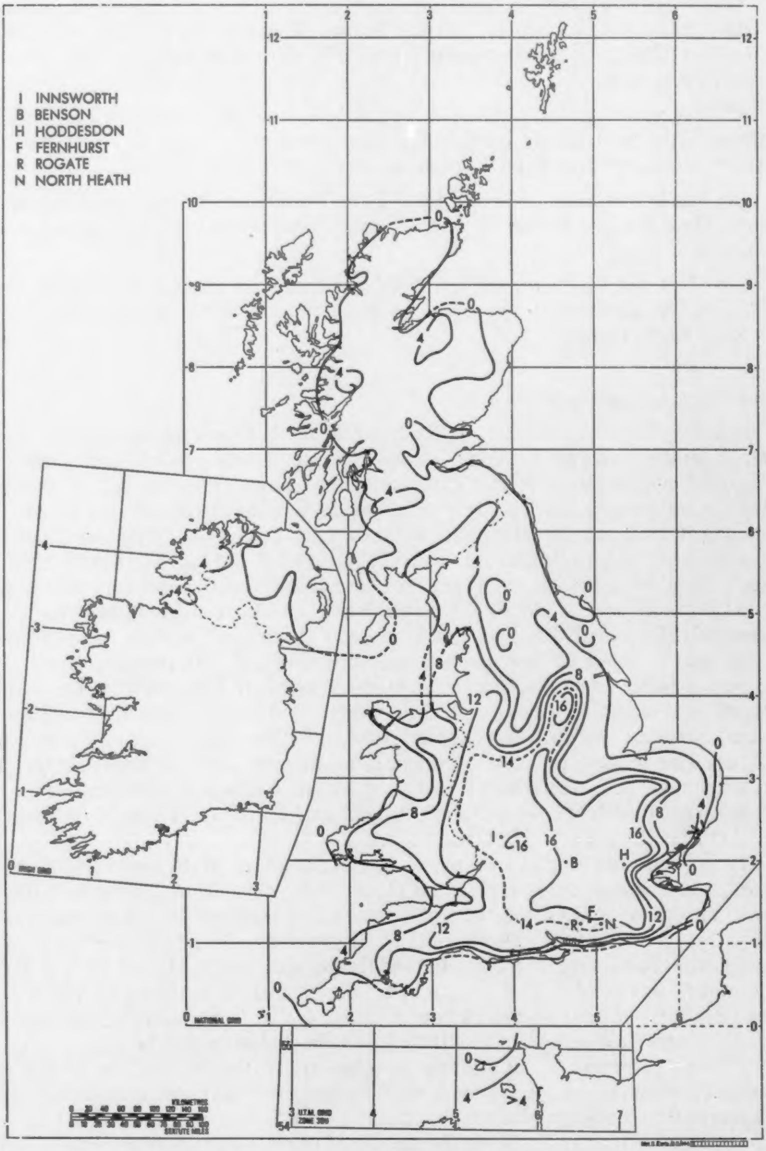

FIGURE 3—NUMBER OF CONSECUTIVE DAYS DURING THE HEAT-WAVE HAVING MAXIMUM TEMPERATURES ⩾28°C (82·4°F)

TABLE IV—SPELLS OF CONSECUTIVE DAYS WITH TEMPERATURE ⩾90°F (32·2°C)

Duration	Dates	Location	Type of screen or stand	Reference
5 days	13–17 June 1868	Tonbridge (Kent)	Non-standard	Fielding (1869)
4 days	2–5 Aug. 1868	Tonbridge	Non-standard	Fielding (1869)
	14–17 July 1876	Beckenham (Kent)	Glaisher	Bicknell (1881)
	31 Aug.–3 Sept. 1906	Greenwich	Glaisher	Bonacina (1947)
		Old Southgate	Stevenson	Butler (1906)
	7–10 July 1934	Bridgwater (Somerset)	Stevenson	Lewis (1934)
	31 May–3 June 1947	Greenwich	Glaisher	Bonacina (1947)
6 days	1–6 July 1976	Innsworth	Stevenson	
		North Heath	Stevenson	
	2–7 July 1976	Cheltenham	Stevenson	
5 days	2–6 July 1976	8 stations	Stevenson	

only two of the spells in the first part of the table were recorded using Stevenson-type screens. Direct comparisons are available between Stevenson and Glaisher readings at Greenwich in 1906 and 1947, and they show that four successive temperatures of 90°F or more were not recorded in the Stevenson screen on either occasion, and if the corrections suggested by Laing are applied to the Tonbridge and Beckenham temperatures these spells also reduce to fewer than four days. On this basis the spells at Old Southgate in 1906 and Bridgwater in 1934 remain as the previous longest, and further evidence of the outstanding heat-wave in 1906 is given by Marriott (1907) in the form of maps of maximum temperatures over the British Isles for each of the four days from 31 August to 3 September 1906. From the maps it appears that maxima exceeded 90°F on each of these days over a substantial area of Cambridgeshire and southern Lincolnshire, but it is not stated whether or not the data were restricted to Stevenson screen readings but merely that the maps were 'based upon the returns from more than 250 stations'.

It seems clear from the above comparisons that, using the criterion of 32°C or 90°F, the 1976 heat-wave far outstripped all previous documented events. At a lower temperature level the sequence of 17 consecutive days (22 June to 8 July inclusive) during which 10 London stations including the North Wall screen at Kew, registered maxima ⩾80°F (26·7°C) also appears to be quite unprecedented in the London area. From the Glaisher stand at Greenwich, Brazell (1968) cited two spells each of 15 days in July 1859 and July 1868, while the previous record at Kew was only 10 days, 5–14 July 1923. Published temperature information of this type is very scarce for stations outside the London area, but it is known that a previous record of 8 consecutive days ⩾30°C set in 1911 at the Radcliffe Observatory, Oxford, has now been superseded by the 1976 spell of 14 days (Samson, 1976).

These are, admittedly, only a few isolated comparisons with past events, but such evidence as there is points inescapably to the conclusion that the June–July heat-wave of 1976 provided the longest unbroken spell of very hot weather since at least the middle of the last century. Before then, temperature comparison, particularly of extremes, becomes progressively more difficult, but Ratcliffe (1976) has suggested that the length of the hot spell may be without equal for at least 250 years.

(c) *The spatial extent of the heat-wave*

Although the hot spell lasted longer and was more intense over central and eastern England then elsewhere, long-standing temperature records were broken at many stations throughout the United Kingdom. Hopkins and Whyte (1975) have published a map giving the extreme maxima (reduced to mean sea level) which may be expected to occur on average only once in 50 years (based largely on an analysis of data from the period 1941–70) and an accompanying graph enabling temperatures for different return period to be estimated. Using these methods a chart (Figure 4) was prepared to show the approximate return period of the extreme maxima recorded during the 1976 event. Over a large area extending across southern England from Land's End to Eastbourne and north through the Welsh Border country to Lancashire a return period of over 50 years is indicated; within this area temperatures corresponding to a return period of 100 years or more were achieved along most of the south coast from Plymouth to Brighton and also over a small area embracing Malvern and Cheltenham. Separate areas at the 50 year level over Norfolk, the Scottish Borders, northern Scotland and the extreme west of Northern Ireland show clearly that the rare nature of the event was in no way confined to the areas from which the highest temperatures were reported. Indeed over much of the latter area, including London, the maximum temperatures reached in 1976 could be expected to recur, on average, every 25 to 50 years although at certain stations (for example Kew) more exceptional maxima were recorded.

Although the 1976 heat-wave occurred rather early in the summer, all-time temperature records were equalled or broken at more than 30 long-period stations (i.e. stations having at least 50 years' data) and these are also marked in Figure 4. They include Stonyhurst (Lancashire), 111 years of data; Southampton and Kew (North Wall screen), 106 years each; Cheltenham, 98 years; Worthing, 96 years. Most of the previous records had been set in the notably hot Augusts of 1911 and 1947. For the month of June the heat in the southern half of the United Kingdom was quite unparalleled. New temperature records for the month were set at 53 out of 70 long-period stations south of a line from Aberystwyth to the Wash, and at 10 of these stations the new record was more than 3°C higher than any previously measured temperature.

3. Coastal temperature variations

Although temperatures at coastal stations were, in general, lower than those inland, Figure 2 shows that unusually high temperatures were recorded along several stretches of coastline; at many places these high values were only reached on one or two days but at several resorts in southern and north-western England temperatures rose higher than 30°C on as many as 8 consecutive days. In both these areas the gradient wind had a strong and persistent offshore component for many days, and before sea-breezes could become established the gradient-controlled winds had first to be overcome. On some days no onshore winds at all were reported from these coasts, while on others, sea-breezes, accompanied by temperature falls of up to 5°C, set in only relatively late in the day after unusually high temperatures had already been attained. Sea temperatures around the coasts of Wales and southern and western England rose by an average of 3°C during the course of the heat-wave to reach a general level of 16 or 17°C.

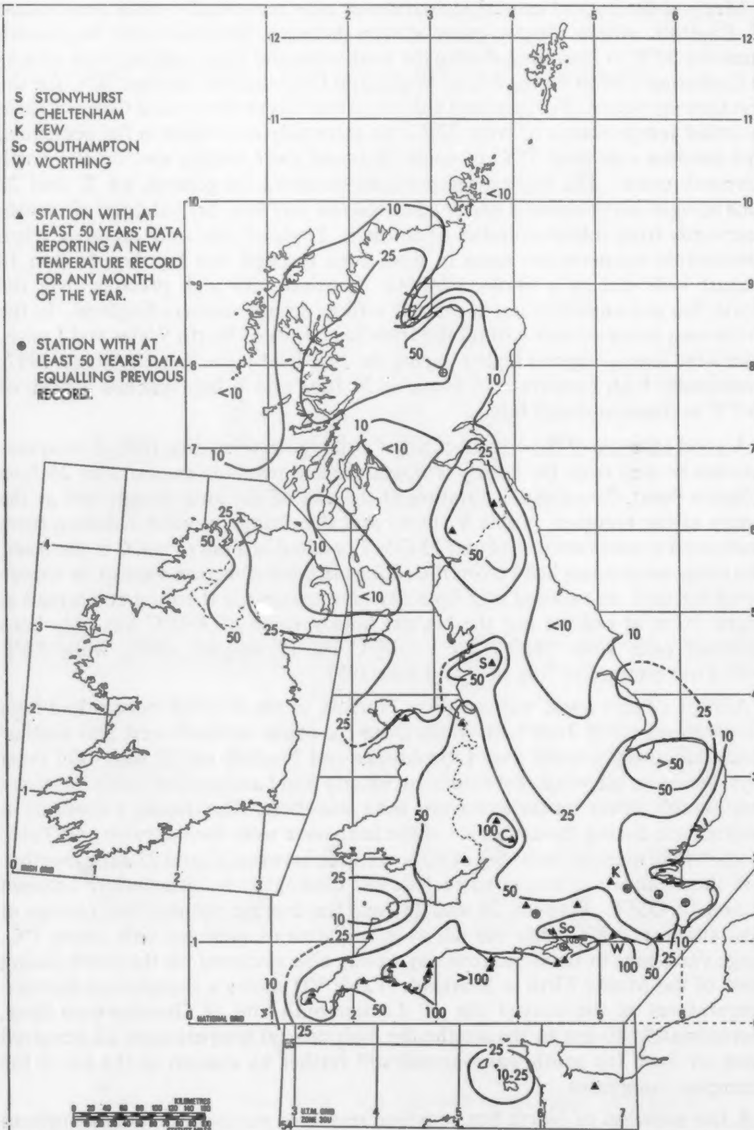

FIGURE 4—ESTIMATED RETURN PERIOD (IN YEARS) OF THE HIGHEST TEMPERATURE DURING THE 1976 HEAT-WAVE

Many of the highest coastal temperatures were reported from the south coast of England, where almost every station between Brighton and Weymouth exceeded 32°C at least once during the heat-wave and even such exposed sites as St Catherine's Point on the Isle of Wight and Portland Bill reached 30°C for the first time on record. Further west almost all stations in Devon and Cornwall also recorded temperatures of over 30°C, an extremely rare event in the peninsula, and maxima exceeded 32°C in some sheltered river valleys and on the north Cornwall coast. The highest temperature occurred, in general, on 27 and 28 June as light north-easterly winds advected the very hot, dry subsided air south-westwards from inland counties of southern England; the only occasion when comparable temperatures seem to have been reached was between 16 and 18 August 1947 during a similar synoptic situation with high pressure over the North Sea and an east to north-easterly airflow across southern England. In the north-west temperatures around the Irish Sea coasts of North Wales and Lancashire were several degrees higher during the 1976 heat-wave than in August 1947; consistently high temperatures between 29 June and 8 July reached a peak of 33·7°C at Blackpool on 3 July.

A good example of the critical effect of a change in wind direction on temperature can be seen from the hourly temperature and wind observations on 26 June at Spurn Point, the coastguard station at the end of the long shingle spit at the mouth of the Humber. Table V shows that the change in wind direction from south-west to east between 14 and 15 GMT resulted in a fall of 6·8°C in the hour. The temperatures reached before the change in wind direction were quite exceptional for such an exposed maritime site. No maximum thermometer is read at Spurn Point at present but the highest hourly value of 30·2°C has only been exceeded once since 1880 (87°F = 30½°C on 18 August 1893), while 86°F (30°C) was attained in July 1911 and June 1957.

Almost all east coast stations from Norfolk to the Scottish border had high temperatures on 26 June with winds from the south or south-west and similiar conditions also prevailed over Lincolnshire and Norfolk on 23 June. On most days, however, the winds were from an easterly point and temperatures remained considerably lower on the east coast than elsewhere. Day-to-day variations in temperature during the early part of the heat-wave were considerable and Table VI shows the maxima recorded at three stations between 22 and 27 June together with the mean winds measured each day at Coningsby in Lincolnshire between 15 and 16 GMT. Between 26 and 27 June the average temperature change at these sites was 8·8°C while the fall at inland stations averaged only about 1°C. Large variations in maxima from day to day also occurred on the north-facing shore of the Moray Firth in Scotland. Table VII shows a comparison between temperatures at the coastal site of Lossiemouth and at Grantown-on-Spey, approximately 40 km to the south; the high coastal temperatures all occurred when air from the south was warmed still further by descent in the lee of the Grampian mountains.

A few stretches of North Sea coastline remained persistently cool throughout the period of the heat-wave. At Aldeburgh (Suffolk) and Gorleston (Norfolk) the temperature never rose as high as 23°C on any day during late June or early July, and on many days the difference in maximum temperature between this section of the East Anglian coast and the nearest inland stations approximately 20 km away was as high as 10°C.

TABLE V—WIND AND TEMPERATURE OBSERVATIONS AT SPURN POINT (NORTH HUMBERSIDE) ON 26 JUNE 1976

Hour GMT	Wind direction (degrees true) and speed (knots)	Temperature °*C*
11	200/05	27·2
12	230/10	29·3
13	230/09	30·2
14	230/05	29·2
15	100/08	22·4
16	Calm	21·9
17	080/05	22·8

TABLE VI—DAILY MAXIMUM TEMPERATURES (°C) AT THREE EAST COAST SITES AND MEAN WINDS AT CONINGSBY BETWEEN 15 AND 16 GMT, 22–27 JUNE 1976

	22nd	23rd	24th	25th	26th	27th
Cromer	25·7	31·2	24·0	26·8	31·8	24·4
Skegness	24·9	29·9	22·0	23·5	29·9	21·0
Cleethorpes	25·0	28·5	25·5	27·5	32·5	22·5
Winds at Coningsby	210/08	230/11	110/09	090/11	240/09	120/06

TABLE VII—DAILY MAXIMUM TEMPERATURES (°C) AT LOSSIEMOUTH AND GRANTOWN-ON-SPEY AND MEAN WINDS AT LOSSIEMOUTH BETWEEN 15 AND 16 GMT, 30 JUNE–10 JULY 1976

	30th	1st	2nd	3rd	4th	5th
Grantown-on-Spey (A)	24·3	29·2	28·3	30·0	23·9	28·8
Lossiemouth (B)	18·6	31·6	21·2	17·2	24·7	30·0
Difference (A) − (B)	5·7	−2·4	7·1	12·8	−0·8	−1·2
Winds at Lossiemouth	070/13	210/08	070/08	070/06	360/07	130/14

	6th	7th	8th	9th	10th
Grantown-on-Spey (A)	29·1	29·9	28·0	27·8	20·2
Lossiemouth (B)	27·1	17·5	18·6	28·8	20·9
Difference (A) − (B)	2·0	12·4	9·4	−1·0	−0·7
Winds at Lossiemouth	010/07	020/07	080/08	130/19	070/06

TABLE VIII—LOWEST REPORTED VALUES OF RELATIVE HUMIDITY (RH) ON 30 JUNE 1976

	Time GMT	RH %	Dry-bulb temperature °*C*	Dew-point °*C*
Honington	1400	08	27·0	−9
Cardington	1700	11	28·5	−5
Stansted	1600	11	27·7	−5
Kew	1600	11	29·2	−5
Boscombe Down	1700	12	29·0	−3
Heathrow	1500	12	30·5	−2
Heathrow	1600	12	29·9	−2

6. Bright sunshine

Durations of bright sunshine during the period of the heat-wave were very high over England and Wales while over Scotland and Northern Ireland totals were well above average in the east and south falling to near average in the north and west. The last nine days of June were almost completely cloudless over the whole of England and Wales but from the beginning of July onwards south-west England and Wales had much more cloud and only average amounts of sunshine. The remainder of England, however, continued to be almost clear of cloud for the first eight days of the month and parts of south and east Scotland also had abundant sunshine during this period.

Taking the 16 day period of the heat-wave as a whole, most of eastern Wales and the whole of England with the exception of south-western counties from Cornwall to Dorset and also parts of the Cumbrian coast had an average of over 12 hours' bright sunshine each day; this figure represents approximately 200 per cent of the 1941–70 average and 70 per cent of the maximum possible sunshine for the time of year. Sunshine amounts increased towards the south-east where most of Kent and East Sussex and also eastern parts of Norfolk and Suffolk exceeded 85 per cent of the possible sunshine, while the Midlands and remaining parts of East Anglia and south-east England recorded between 80 and 85 per cent.

The highest sunshine totals for the 16 day period from 23 June to 8 July inclusive, and the percentages of possible sunshine, were as follows:

227·8 hours at Scole (Norfolk)	87·5%
227·6 hours at Wattisham (Suffolk)	87·8%
227·4 hours at Eastbourne (East Sussex)	88·9%
227·1 hours at Bexhill (East Sussex)	88·8%
226·1 hours at Folkestone (Kent)	88·2%
225·8 hours at Hastings (East Sussex)	88·1%
225·3 hours at Wye (Kent)	87·6%
224·3 hours at Lowestoft (Suffolk)	86·4%.

The highest percentage of the 1941–70 average sunshine during this period occurred in north-west England and the north Midlands where Manchester had 239 per cent and Nottingham 235 per cent of average (Ratcliffe, 1976).

7. Very low humidities during the heat-wave

Throughout most of the heat-wave relative humidities at inland sites at the time of maximum heating were in the range 25 to 35 per cent, comparable with those recorded during the hot spells of August 1975 and August 1976 and well below the average for very hot weather. The average wet-bulb depression during the heat-wave at Heathrow, Honington and Birmingham (Elmdon) was 11·2°C and this compares with a 1960–74 average of 9·2°C for occasions when temperatures exceeded 28°C. On three days relative humidities of less than 20 per cent were observed quite widely over central and southern England and most notably on 30 June when exceptionally dry air was observed at the surface for several hours over a considerable area from East Anglia to south-west England. Figure 5 shows the minimum relative humidity recorded at stations in southern England and South Wales on 30 June (as calculated from hourly dry- and wet-bulb temperatures using hygrometric tables) and the lowest values overall are listed in Table VIII. At Heathrow the relative humidity remained below 15 per cent for 5 consecutive hours, at Cardington for 4 hours and at Stansted, Kew and Honington for 3 hours.

To face page 344

Photograph by C. A. Stumbles

PLATE I—STRATOCUMULUS UNDULATUS AT ST MAWGAN

(See page 360.)

PLATE II—PARTICIPANTS IN THE CIMO VII MEETING, HAMBURG, 1–12 AUGUST 1977

From left to right: Dr D. N. Axford (UK), Mr G. W. Kronebach (WMO Secretariat) and Mr A. H. Hooper (UK) (see page 356).

Photographs by Conti-Press, Hamburg

PLATE III—EXHIBITORS' STANDS AT THE METEOREX 77 EXHIBITION, HAMBURG (See page 356).

PLATE IV—CIMO VII GROUP, HAMBURG, 1–12 AUGUST 1977

Dr D. N. Axford is in the back row, immediately to the right of the tree trunk; Lt Cdr R. A. Young, RN is standing next to Dr Axford on the reader's right, and Mr A. H. Hooper is seventh from the left in the second row counting from the front. (See page 356.)

To face page 345

PLATE V—TECIMO GROUP, HAMBURG, 27–30 JULY 1977

Dr D. N. Axford is at the extreme left of the second row counting from the front, Mr A. H. Hooper is also in this row, and Lt Cdr R. A. Young, RN is in the middle of the back row. Dr M. Hinzpeter, Mr H. Treussart and Mr G. W. Kronebach are standing together in the middle of the front row. (See page 356).

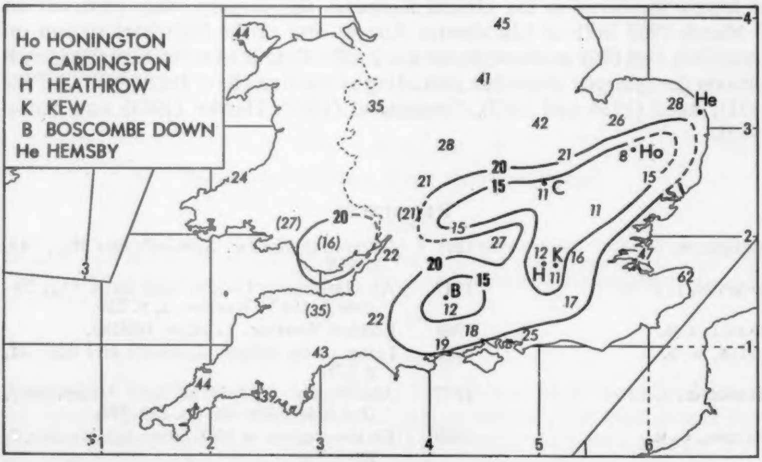

FIGURE 5—LOWEST VALUES OF RELATIVE HUMIDITY REPORTED ON 30 JUNE 1976

Bracketed figures refer to stations which report only at certain fixed hours.

The 11 GMT radiosonde ascent at Hemsby showed a layer of very dry air above 1010 mb (approximately 150 m), the lowest dew-point being −18°C at a height of approximately 750 m, and a very similar sounding was also obtained at Cardington earlier in the morning at 0540 GMT. A trajectory analysis showed the source of this air to be the large anticyclone which had been almost stationary over the central North Sea for several days. The minimum reported humidities at the surface were very close to those shown on the two ascents and it is clear that a considerable mass of the dry air was, most unusually, brought from a height of several hundred metres right down to the surface on 30 June, probably by a combination of further anticyclonic subsidence and mixing of the air in the lowest layers in 10 to 20 knot north-easterly winds. Timing of the arrival of very dry air at different stations seems to indicate that several different masses of air were probably brought to the surface in different parts of southern England and South Wales during the day, although many reports can be explained by a spread of dry air south-westwards from a single source over East Anglia.

Apart from 30 June very dry surface air was reported on 2 July and 7 July. On both days relative humidities of less than 20 per cent were recorded for several consecutive hours over parts of East Anglia and on the 7th the area of low humidities discussed by Hunt (1977) extended across much of the Midlands also. The lowest values of relative humidity reported on these days (as calculated from hourly dry- and wet-bulb readings) were 14 per cent at Honington on both 2 and 7 July and 15 per cent at Cardington and Birmingham (Elmdon) on 7 July.

To put all these low values into the context of previous such occasions, the Climatological Atlas of Great Britain (1952) lists 5 days between the years 1921 and 1942 on which relative humidities of less than 20 per cent were measured over southern England. More recently values of only 4 per cent, believed to be

the lowest measured in the United Kingdom this century, were observed on 29 March 1965 both at Manchester Airport and at the high-level station on Great Dun Fell (847 m above mean sea level). Details of these occasions, with notes on the synoptic situations prevailing at the time, have been given by Pick (1931), Read (1934 and 1942), Drummond (1942), Hawke (1944) and Suttie (1965).

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MARKED BACKING OF WESTERLY AND NORTH-WESTERLY WINDS OVER THE IRISH SEA DUE TO DIFFERENTIAL HEATING OVER LAND AND SEA

By A. K. KEMP

(Meteorological Office, Royal Air Force, Valley)

SUMMARY

It has been noticed at Valley that in summer if the surface wind during the morning is between west and north-west, by afternoon the wind has usually backed to south-west. This article attempts to explain this phenomenon and investigates the statistical significance of its occurrences.

INTRODUCTION

The forecast for the afternoon of 10 July 1969 seemed ideal for a first sail with my family on my newly acquired small sailing cruiser. The wind should have been west-north-west force 4, which would have made the waters near the south coast of Holyhead Island well sheltered, and should have ensured a comfortable night at anchor in Rhoscolyn Cove, which is only exposed to the south.

As we left the shelter of the straits between Holyhead Island and Anglesey and entered the open sea, I found that instead of an easy sail on smooth waters we faced a beat against a force 4–5 south-westerly wind and a short steep chop. Later in the afternoon conditions at Rhoscolyn anchorage were almost untenable and my wife quickly vetoed any idea of cooking a meal aboard. After a thoroughly miserable evening with the crew close to mutiny, relief came around dusk as the wind veered to the west; the sea soon became calm and a peaceful night followed.

The next day almost the same sequence of events occurred and with my reputation as a forecaster and skipper at stake, I was strongly motivated to find out why my wind forecasts had been so badly wrong!

INVESTIGATION

During the period 10–12 July 1969 a large anticyclone became established to the south of Ireland (see Figure 1) and a warm rather moist west-north-westerly airstream spread across the British Isles. Western coastal areas remained mainly cloudly but over many inland and eastern areas the afternoons became warm and sunny. Figures 2, 3, 4 and 5 show isobars and isotherms for 10 July and 00 GMT on 11 July (although isotherms over the Welsh hills will be much more complex than shown here). The formation of an isobaric trough between 12 and 18 GMT close to the east coast of Ireland is clearly indicated and this trough can be closely related to the marked thermal high over eastern Ireland, the strong thermal gradient just east of the Irish coast and the relatively low surface temperatures over the coast of west Wales. By 00 GMT on 11 July the isobaric trough has disappeared as have the strong thermal gradients. This sequence of events was repeated on the following two days as can be seen from Figure 6. Here the surface wind direction at Valley and the temperature difference between Dublin and Valley are plotted against time. The two stations are well situated to indicate the strength of the thermal gradients across the Irish

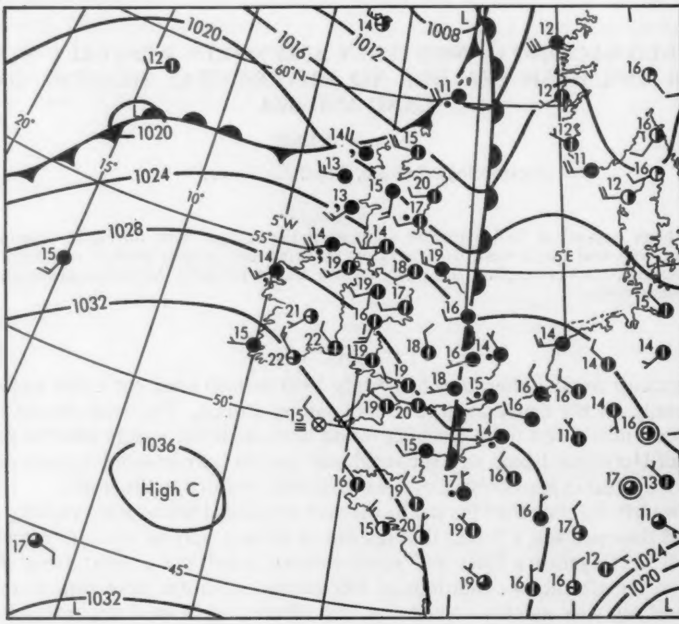

FIGURE 1—SYNOPTIC SITUATION AT 18 GMT ON 10 JULY 1969

Sea. On each day the maximum backing at Valley occurred at about 18 GMT, about or soon after the time at which the maximum temperature would be occurring over land.

The two series show a high negative correlation of —0·87 (dominated by the short-period changes rather than by the long-period change) which for the sample of 21 pairs has less than one chance in 1000 of arising by accident if there is really no relationship between them. Although it seems unlikely it is, of course, possible that the relationship is less direct than has been supposed and that the effect is due to some third factor which is common to both. At least they exhibit a high degree of covariation.

The basic reason for the formation of the isobaric trough appears to be differential heating between land and sea, and in summer this will tend to occur every day except under completely overcast conditions. A simple method of investigating this is to consider wind changes which occur at Valley between 09 and 18 GMT and relate these changes to the temperature difference between Valley and Dublin. If two periods are chosen, one winter and one summer, then the probability of westerly surface winds backing in summer should be much higher than in winter.

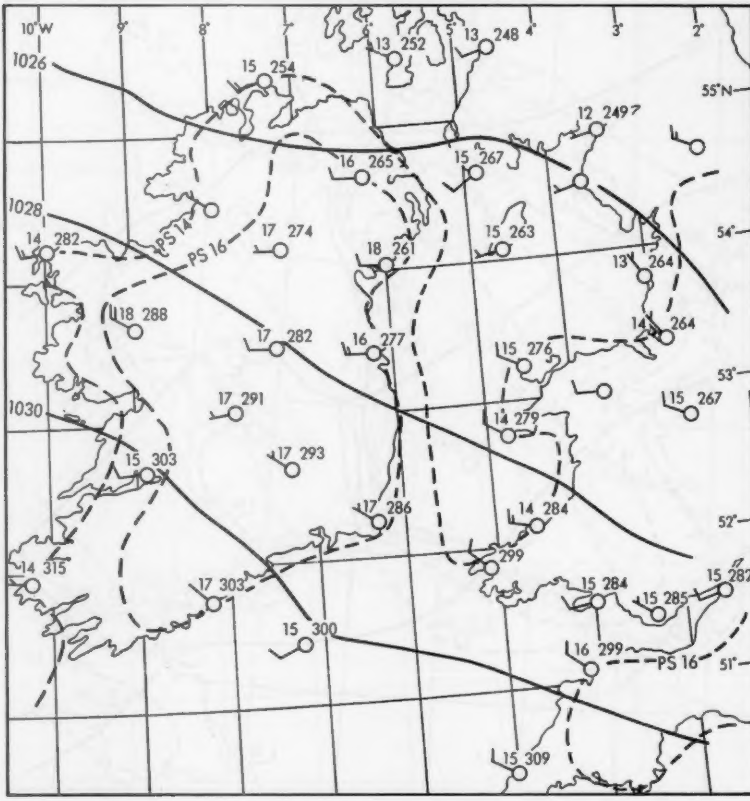

FIGURE 2—SYNOPTIC SITUATION AT 09 GMT ON 10 JULY 1969

——— isobars - - - - isotherms

A ten year period was chosen, 1965 to 1974, and a computer print-out obtained of all days when the 09 GMT wind at Valley was 10 knots or greater and between 260° and 320°. The periods selected were December to February and June to 15 August inclusive. The choice of directions was not critical and speeds of 10 knots or greater were considered to avoid days of light variable winds and possible large effects from sea-breezes. (The sea-breeze at Valley frequently occurs on days with light gradients. It usually sets in as a south-westerly wind which soon veers to north-west.) The second half of August was excluded because with decreasing solar radiation at this time and with sea temperatures close to a maximum, strong thermal gradients between land and sea are less likely to occur.

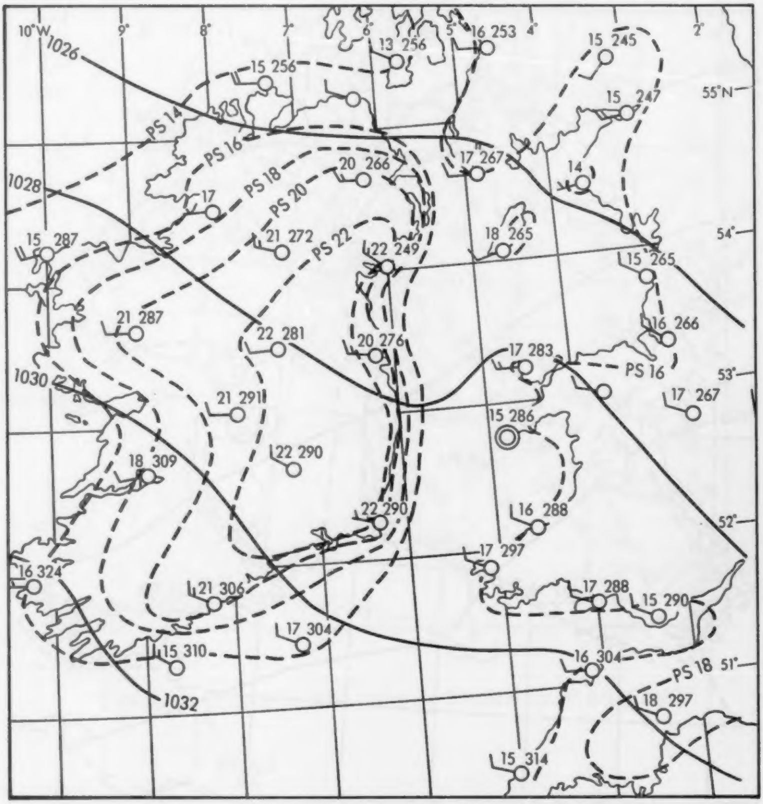

FIGURE 3—SYNOPTIC SITUATION AT 12 GMT ON 10 JULY 1969

——— isobars - - - - isotherms

In the latitude of the British Isles, the prevailing trough/ridge pattern associated with mobile westerlies implies that a north-westerly wind is more likely to back than to veer over a period of say 9 hours. In an attempt to eliminate this natural backing tendency it was decided to exclude from the investigation all days when a front, frontal trough or closed isobar was crossing Ireland or the Irish Sea. This would also exclude most days with thick frontal cloud when differential heating would be minimal. In practice the selection of such days was made by examining the 12 and 18 GMT charts as drawn on the *Daily Weather Reports* (*DWR*s) and considering the area defined by 4½°W, 10½°W and 51½°N, 55½°N.

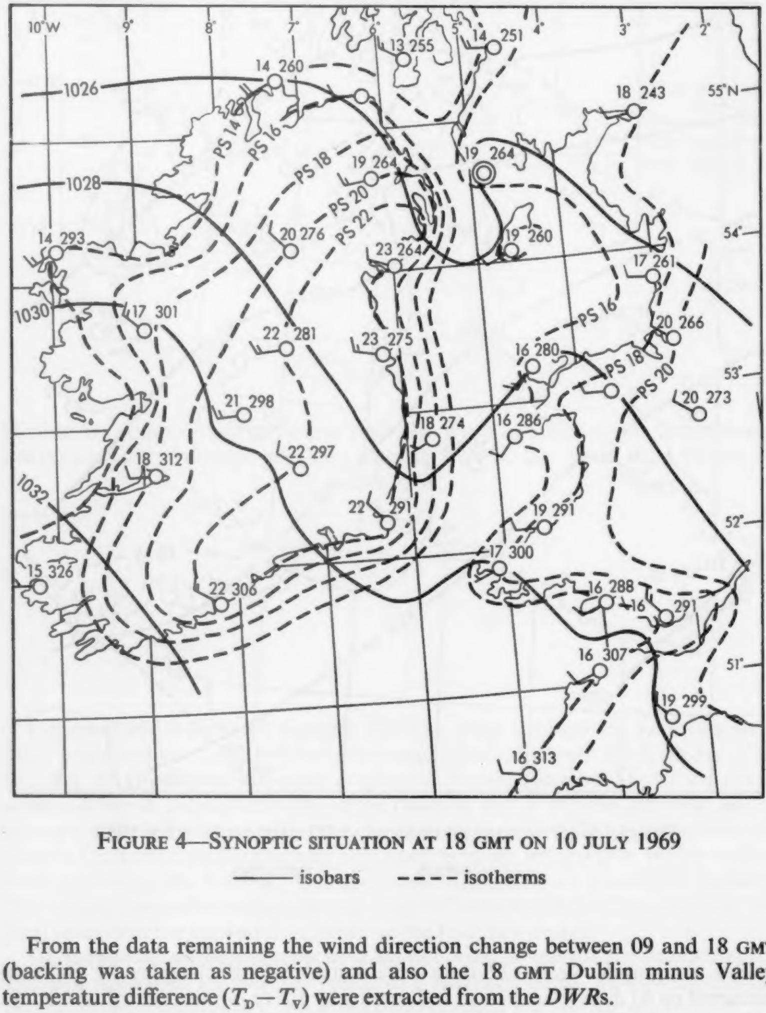

FIGURE 4—SYNOPTIC SITUATION AT 18 GMT ON 10 JULY 1969

——— isobars - - - - isotherms

From the data remaining the wind direction change between 09 and 18 GMT (backing was taken as negative) and also the 18 GMT Dublin minus Valley temperature difference (T_D-T_V) were extracted from the *DWR*s.

RESULTS AND DISCUSSION

Figure 7 shows a plot of all the data. The two sets of results show striking differences.

For the winter period 109 days were considered. Backing by 10° or more occurred on 43 days (39 per cent) and veering by 10° or more occurred on 45 days (41 per cent) i.e. no bias towards backing is evident. The mean value of T_D-T_V was —1·7°C partly because by 18 GMT in winter rapid diurnal cooling is occurring at Dublin whereas at Valley with the wind off the sea little change is taking place.

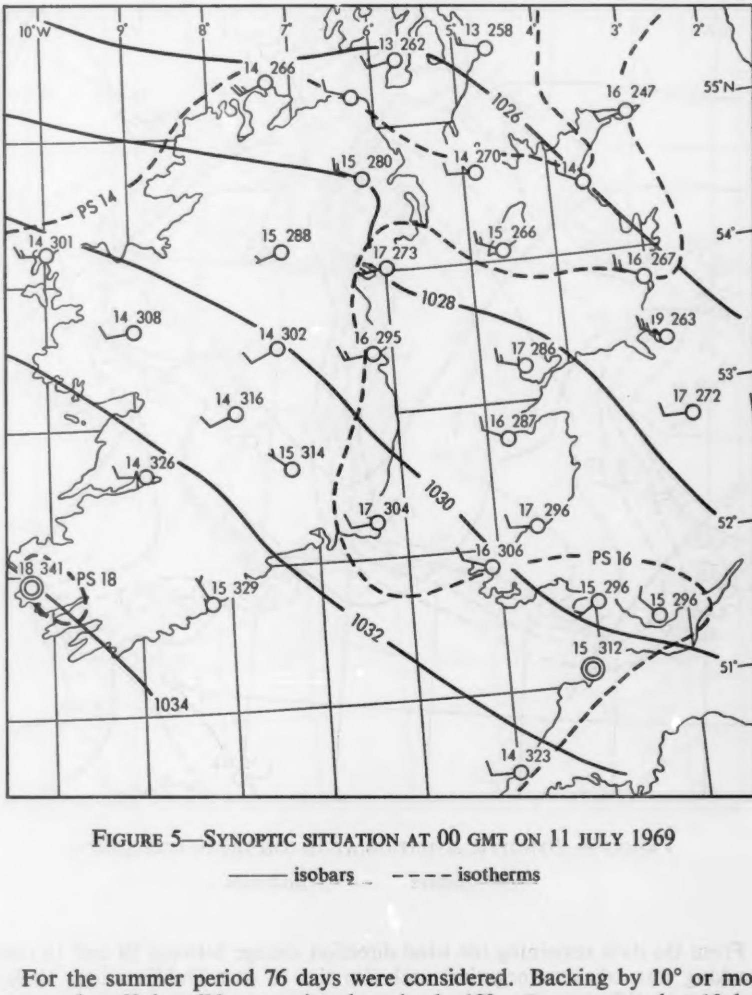

FIGURE 5—SYNOPTIC SITUATION AT 00 GMT ON 11 JULY 1969

——— isobars - - - - isotherms

For the summer period 76 days were considered. Backing by 10° or more occurred on 63 days (83 per cent) and veering by 10° or more occurred on 12 days (16 per cent). The mean backing was 47° and the standard deviation 40°. A statistical *t*-test on the null hypothesis that there is no bias towards backing indicates that such a large mean has less than 1 chance in 1000 of arising by accident of the sample. The mean value of $T_D - T_V$ was 1·3°C. However, over this sample, which includes a variety of synoptic situations (rather than the single situation prevailing from 10 to 12 June 1969) the amount of backing is not closely related to the temperature difference. At times large values of backing occurred with only a small $T_D - T_V$ value. Nevertheless a linear regression of $T_D - T_V$ on the change of wind direction yields a correlation of 0·25 which is statistically significant at the 5 per cent level.

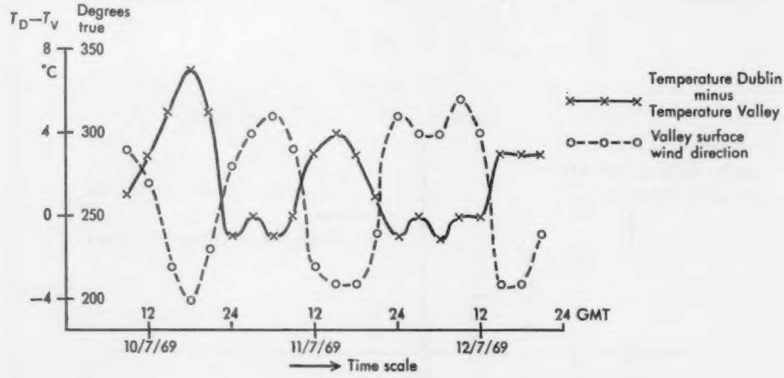

FIGURE 6—ASSOCIATION BETWEEN SURFACE WIND DIRECTION AT VALLEY AND TEMPERATURE DIFFERENCE BETWEEN DUBLIN AND VALLEY FROM 10 JUNE TO 12 JUNE 1969

Figures 8 and 9 show an example of a day when temperature gradients were fairly weak and yet a marked isobaric trough developed over the Irish Sea. On this day the air mass was of polar origin, and showers occurred in the windward coastal areas of Ireland throughout the previous night. By mid morning, as the showers extended to eastern Ireland, a minor pressure trough developed near the eastern Irish coast and apparently remained between Ireland and Wales until it died out during the evening. It is suggested (without much theoretical support) that strong convection occurring over land will lead to a fall of pressure over the land relative to the sea and thus reinforce the Irish Sea trough.

On the few occasions when backing did not occur, it was usually found that the gradient wind over Ireland had veered to a northerly point. This meant that the thermal trough development occurred over southern and not eastern Ireland.

Although the results obtained apply strictly to Valley only, it is probable that they could usefully be applied to the Irish Sea and the west coat of Wales, south of Anglesey. For example, in summer sailing races take place frequently between Holyhead and Dun Laoghaire (near Dublin). It would be of considerable advantage for a competitor to know that despite a shipping forecast giving north-westerly winds, the winds over the route during the afternoon would very likely be south-westerly. Similar effects should occur over any similar land–sea configuration. Thus for example it might be possible to demonstrate that, with northerly winds over the English Channel area, surface winds tended to back to westerly over coastal areas of northern France during summer afternoons.

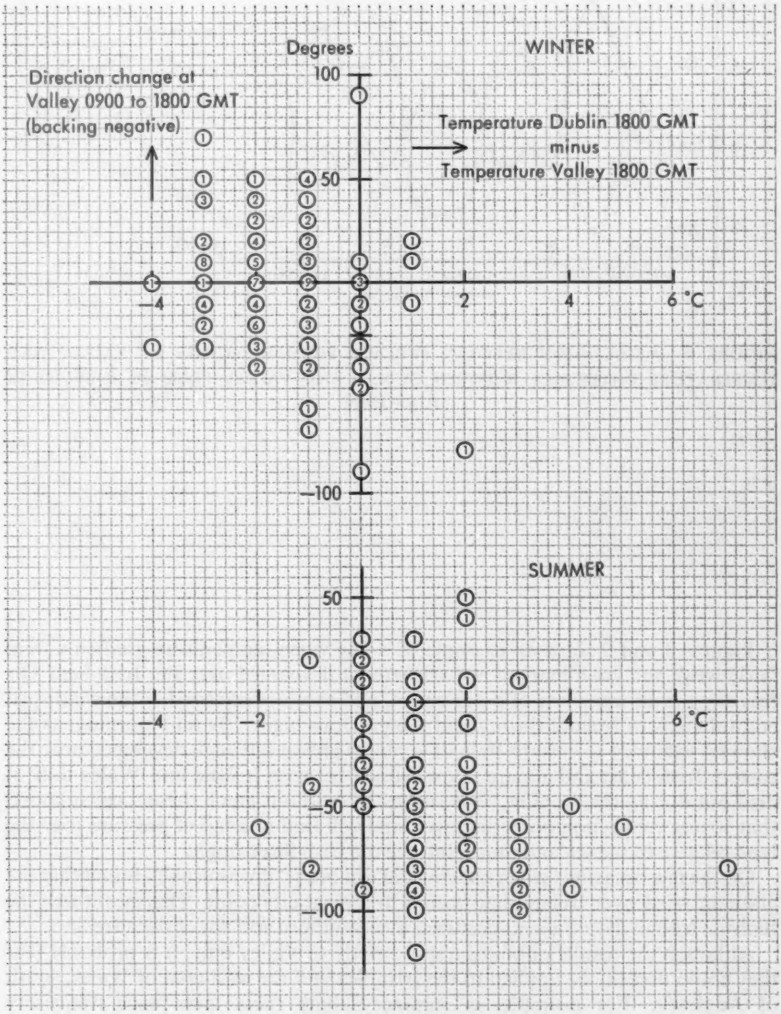

FIGURE 7—RELATION BETWEEN DIRECTION CHANGE AT VALLEY FROM 09 TO 18 GMT AND TEMPERATURE DIFFERENCE BETWEEN DUBLIN AND VALLEY AT 18 GMT

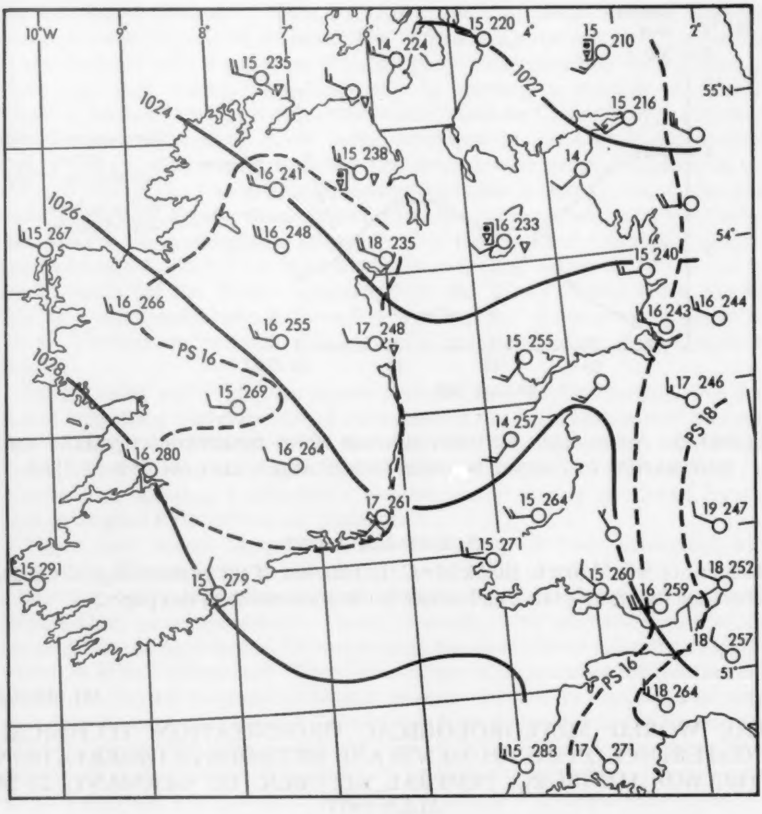

FIGURE 8—SYNOPTIC SITUATION AT 15 GMT ON 27 JUNE 1969

——— isobars - - - - isotherms

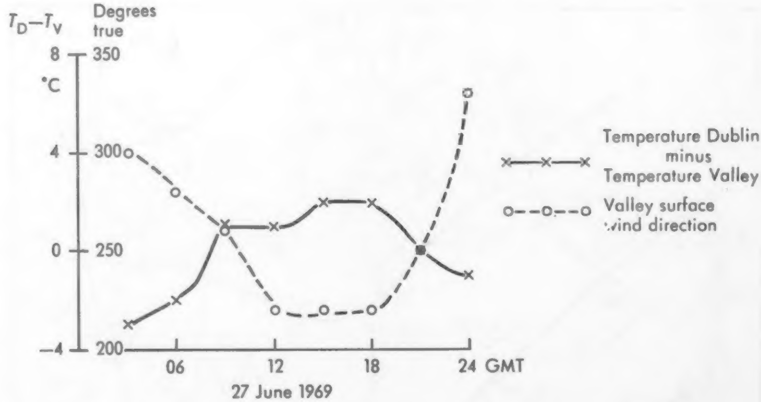

FIGURE 9—ASSOCIATION BETWEEN SURFACE WIND DIRECTION AT VALLEY AND TEMPERATURE DIFFERENCE BETWEEN DUBLIN AND VALLEY ON 27 JUNE 1969

ACKNOWLEDGEMENT

The author would like to thank Mr C. L. Hawson of the Meteorological Office, Bracknell for his assistance and advice in the preparation of this paper.

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THE WORLD METEOROLOGICAL ORGANIZATION TECHNICAL CONFERENCE ON INSTRUMENTS AND METHODS OF OBSERVATION (TECIMO), HAMBURG, FEDERAL REPUBLIC OF GERMANY, 27–30 JULY 1977

By D. N. AXFORD

A Technical Conference on Instruments and Methods of Observation (TECIMO) was held in Hamburg from 27 to 30 July 1977. The conference was arranged to precede the seventh session of the WMO Commission for Instruments and Methods of Observation (CIMO VII) which was also held in Hamburg from 1 to 12 August 1977. In parallel an international exhibition of instruments (METEOREX 77) was organized by the host country from 28 July to 3 August, thus covering the last three days of TECIMO and the first three days of CIMO VII.

The Technical Conference was well attended, with over 120 participants from more than 35 countries. The UK delegation consisted of Dr D. N. Axford, (Assistant Director, Operational Instrumentation), Mr A. H. Hooper (Observational Requirements and Practices Branch) (both of the Meteorological Office) and Lt Cdr R. A. Young, RN (Directorate of Naval Oceanography and Meteorology). It was opened at 9.30 a.m. on Wednesday 27 July 1977 with speeches of welcome from Mr H. Treussart, the President of CIMO and Dr M. Hinzpeter,

the Conference Director. This first day of the conference was introductory, covering a wide variety of subjects. The United Kingdom was well represented in the morning with a paper on the joint project organized by the Institute of Hydrology and Heriot-Watt University to develop a suitable Automatic Weather Station (AWS) for the severe environment on Cairn Gorm, a paper on the microprocessor-based AWS being developed in the UK Meteorological Office, and a further paper on the Mk 3 radiosonde with special emphasis on the software involved. The afternoon session included a description of the new facilities for atmospheric research and instrument comparisons which are being installed for the Atmospheric Observatory of the National Center for Atmospheric Research (NCAR) at Boulder, Colorado, USA, an up-to-date review by Dr E. Jatila (of the WMO Secretariat) of the WMO FGGE (First GARP Global Experiment) Navaid Sounding System, and an interesting paper by Mr H. Treussart on methods of transmission and presentation of weather radar data.

On Thursday and Friday the papers were divided into four themes. The first theme concerned 'Development of New Sensors for Basic Parameters' and was chaired by Dr M. Hinzpeter. In fact there was little sign of any new breakthrough in this area, although the session was enlivened by a fascinating five minute film showing a composite weather radar display produced by the Meteorological Research Unit at Malvern.

The second theme 'Acquisition and Processing of Data associated with Automatic Surface Systems' was chaired by Mr A. H. Hooper (UK). Here the continuing world-wide progress and development of AWS became apparent. Papers from (amongst others) France, Canada, New Zealand and Finland showed that the requirement for automating the measurement of meteorological variables is well recognized. There is a variety of approaches for meeting this need. Hardwired modular analogue systems for use in remote sites were described by participants from Canada and New Zealand, and the French and Finnish papers described micro-computer-based AWS similar to those being developed in the United Kingdom. A particularly interesting paper (in the writer's opinion) was that by D. J. McKay and J. D. McTaggart-Cowan on 'An intercomparison of radiation shields (screens) for AWS'. It described a trial involving an array of 19 sensors and screens varying from the standard Stevenson screen to the Israeli Thaller screen, and the measurement of the distribution of temperature errors in the various screens from an accurate reference temperature. Much comment was provoked by the histograms of the various mean hourly errors, and of maximum and minimum errors. They showed 90 per cent of hourly readings within $\pm 0{\cdot}5°C$ of the reference for all screens, and for some screens 90 per cent of hourly readings are within $\pm 0{\cdot}2°C$ of the reference (which meets the WMO requirements for automatic weather stations). It was clear that none of the available screens, ventilated or unventilated, meet the stated WMO requirement of $\pm 0{\cdot}1°C$ for synoptic measurements.

The third theme 'Methods of measuring upper-air parameters, direct and remote techniques' was chaired by Dr F. Finger (USA). It was interesting to hear the French and Americans describing their automated and semi-automated systems, and to recognize that the United Kingdom Meteorological Office has not been alone in finding the road to a fully automated upper-air system to be long and difficult. A paper from the USSR described a different approach in which the raw data from three sonde stations are fed to a centralized computer

system for processing. A lot of discussion was generated by Mr E. A. Spackman's (UK) paper on 'The Compatibility and Performance of Radiosonde Measurements of Geopotential Height in the Lower Stratosphere'. The paper describes results from a computer program which, twice a day since 1975 for a large number of radiosonde stations in the northern hemisphere, has been measuring the difference between (a) values of the geopotential of the 100 mb and other stratospheric standard levels as reported by the stations and (b) values at the same points derived from the objective computer analysis. Differences have also been measured between observed geopotentials at 00 GMT and 12 GMT for each of the radiosonde stations. The results showed interesting variations between one sonde type and another, between the various national results, and even between one large area and another using the same sonde. Discussion centred around the feasibility of these results being fed back on a routine basis to the regional national centres in order that corrections can be applied where necessary.

The final session was on the 'General Operational Aspects of Meteorological Instrumentation' and was chaired by Dr D. G. Rozhdestvensky (USSR). It included a summary paper by Dr H. Yates (USA) on the new generation of US Operational Satellites.

In the intervals between the formal papers and proceedings, and also after they were all concluded, there was time to visit the METEOREX 77 Exhibition where 80 exhibitors and firms had stands and displays covering all aspects of meteorological instrumentation. This was particularly useful in that various points arising from some of the papers could be taken up immediately with the designer or manufacturer. For example the Canadians' description of their low-level Mini-Sonde System was greatly enhanced by a quick visit to see it on the Canadian stand. This overlapping of conference, exhibition and CIMO itself was greatly appreciated.

The organization and administration of the conference and exhibition, under the direction of Dr M. Hinzpeter and the National Meteorological Institute of the Federal Republic of Germany was excellent. The UK participants found the conference papers, the exhibition and the numerous discussions with other workers in the same field stimulating and enjoyable, and, of course, there was also the opportunity to see the sights of the City of Hamburg, which has beautiful parks and lakes, and to verify the words of the song 'In Hamburg sind die Nächte lang'. (See Plates II–V.)

REVIEWS

The physics of atmospheres, by J. T. Houghton, 240 mm × 170 mm, pp. xiii + 203, *illus.,* Cambridge University Press, Bentley House, 200 Euston Rd, London NW1 2DB, 1977. Price: £6.50.

In this small book Professor Houghton attempts to introduce the major areas of study involved in the physics of electrically neutral atmospheres to undergraduate and postgraduate students. Although the treatment is brief, this aim is achieved. Much of the book is devoted to radiative processes and in addition to being an introduction to this topic the book will be a reference for non-specialists.

Basic ideas and simple radiative-equilibrium models are treated in the first two chapters and a chapter on thermodynamics introduces the effects of water vapour on atmospheric structure. This chapter also includes a discussion of the components of the atmospheric energy budget but this would have been better included in the dynamics section where related topics are discussed.

The treatment of the upper atmosphere is a catalogue of the physical processes in this region and although the range of processes is made clear the relative importance of each mechanism is not obvious. The section requires a more extensive background knowledge than most of the others. The condensation and coalescence mechanisms of droplet growth are described under the title 'clouds' but the important dynamical processes are ignored. The effects of cloud on radiative transfer are described in some detail but the influence of radiation in creating fogs is not mentioned.

Almost half-way through the book the subject of dynamics is introduced with an explanation of partial derivatives and a derivation of the equations of motion in a rotating frame of reference. The geostrophic approximation and the thermal wind equation are derived in a conventional manner. Perturbation methods are used in the subsequent chapter to obtain wave solutions of these equations with carefully stated approximations. This will form a useful introduction to the subject although the inclusion of the diagram, from a COSPAR report, purporting to show gravity waves, will not aid the interpretation of these ideas. Turbulence is introduced in Chapter 9 by reference to the turbulent boundary layer and the author develops the theories of eddy stresses and the Ekman spiral. The treatment is basic but can be extended through the use of problems at the end of the chapter. The turbulent nature of larger-scale flows, both two- and three-dimensional and the energy spectrum are briefly mentioned.

Barotropic and baroclinic instability are discussed in a chapter on the general circulation and some fundamental properties are derived for systems of simple geometry but there is little to relate them to atmospheric observation. An account of the development of numerical models is given but this is confined to models of large-scale flows. Mesoscale and smaller-scale models, and the differences in the physics on such scales are scarcely mentioned. The treatment of the so-called physical processes in numerical models is rather unbalanced, with an extensive treatment of radiation, but convection (not all models use a simple convective adjustment) and the effects of topography (not all models employ sigma co-ordinates) are confined to single paragraphs. The observations required for numerical models during the Global Atmospheric Research Program (GARP) are discussed in the subsequent chapter. A good basic account is given of the retrieval of temperature and atmospheric-composition data from satellite observations but the remote determination of surface pressure or winds is not discussed. The final chapter on atmospheric predictability describes attempts being made to improve numerical models but in my opinion fails to emphasize the necessity of undertaking fundamental studies of the processes determining the predicability of the atmosphere.

An extensive and up-to-date bibliography is provided and in an appendix extensive tables of atmospheric properties are given but in a book of this type it is doubtful whether tables of model atmospheres or spectral-band information are necessary.

To summarize, this is a readable book which provides a useful summary of the many processes occurring in the atmosphere. It is well presented with generally

clear diagrams and the problems provided to amplify and extend the text will be appreciated. The main drawback of the book, as with many attempts to summarize a wide field, is the lack of balance, reflecting as it does the author's interests. The book will be a useful introduction to radiative processes for many, and indeed may serve as a reference in this subject to the non-specialist. It is to be hoped that the remainder will sufficiently whet the appetite of the reader that he will be encouraged to read the more detailed books and papers referred to.

P. R. JONAS

Stratocumulus undulatus at St Mawgan

The photograph which is reproduced as Plate I in this issue was taken at St Mawgan, Cornwall at 0819 GMT on 20 April 1977 looking in a north-easterly direction. The cloud is a good example of stratocumulus undulatus. At the time of the photograph the surface wind was 210° 7 kn, dry-bulb temperature 10·4°C, wet-bulb temperature 9·2°C, relative humidity 85 per cent, and MSL pressure 1030·6 mb. The cloud was estimated to be at about 3500 ft ($\approx$1000 m). The surface analysis for 00 GMT shows a slow-moving very weak warm front oriented SW/NE and lying close to St Mawgan. The radiosonde ascent made at the same time at Camborne shows an inversion and increase in moisture at 890 mb which was obviously associated with the front; the stratocumulus appeared to form near this inversion.

C. A. STUMBLES

Obituary

It is with great regret that we have to record the death on 9 June 1977 of Dr T. W. Harrold, Principal Scientific Officer, of the Operational Instrumentation Branch (Met O 16).

Terry Harrold joined the Office in 1961 and from 1962 to 1971 was stationed at the Meteorological Research Unit at Malvern where he worked on a variety of problems involving the use of radar. His great ability and the quality of his published work on the measurement of rainfall and frontal air motion, and on severe storms in Oklahoma, were recognized in 1967 by the award of the L.G. Groves Second Memorial Award. In 1971 he took the degree of Ph.D. of London University (Imperial College). In 1972 he was awarded the Buchan Prize of the Royal Meteorological Society jointly with Dr K. A. Browning.

In October 1971 Dr Harrold was promoted P.S.O. and joined the Agriculture and Hydrometeorology Branch where he was put in charge of the Meteorological Office team concerned with the Dee Weather Radar Project; he made a major contribution to the success of the project which demonstrated the ability of radar to provide good estimates of areal rainfall over hilly terrain.

In August 1975 he was posted to the Operational Instrumentation Branch where he worked on the development of automatic weather stations for use on land and at sea.

In addition to having high scientific ability, and the gift of thinking quickly and clearly, Terry Harrold was possessed of much personal charm; colleagues who sought his help and co-operation or who talked to him socially always felt they had his complete attention.

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CONTENTS

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